
HQ&L 2004
Perspectives
Chris Quigg

Thank you!

To our Puerto Rican hosts . . .

- ▷ Local organizing committee and conference staff

To the conference organizers . . .

- ▷ For the diverse, coherent, & stimulating scientific program

To all the speakers . . .

- ▷ For thoughtful and well-organized presentations, rich in content

To the sponsors . . .

- ▷ For supporting HQ&L 2004

To the taxpayers of the world . . .

- ▷ For supporting our research

Special thanks . . .

To accelerator scientists . . .

▷ For innovations and heroic work

KEK–B, PEP–II, CESR

Tevatron, HERA, DAΦNE

. . . and all our laboratories

Helen Quinn's Deep Questions

- ▷ Why are there multiple generations?
- ▷ Do the patterns of mass and mixing tell us anything?
- ▷ Can we understand the CP asymmetry of the Universe?

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Galileo's Minute Particular

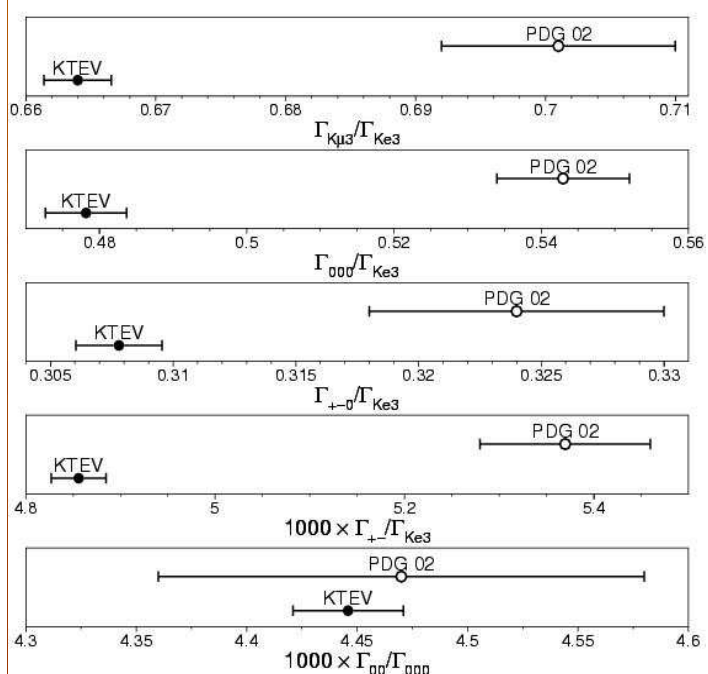
Io stimo più il trovar un vero, benchè di cosa leggiera, ch'l disputar lungamente delle massime questioni senza conseguir verità nissuna.

Not asking general questions and receiving limited answers, but asking limited questions and finding general answers

V_{us} *(and ingredients)*

Nagging unitarity problem ($|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \neq 1$) has prompted reëxamination of V_{ud} and new studies of V_{us}

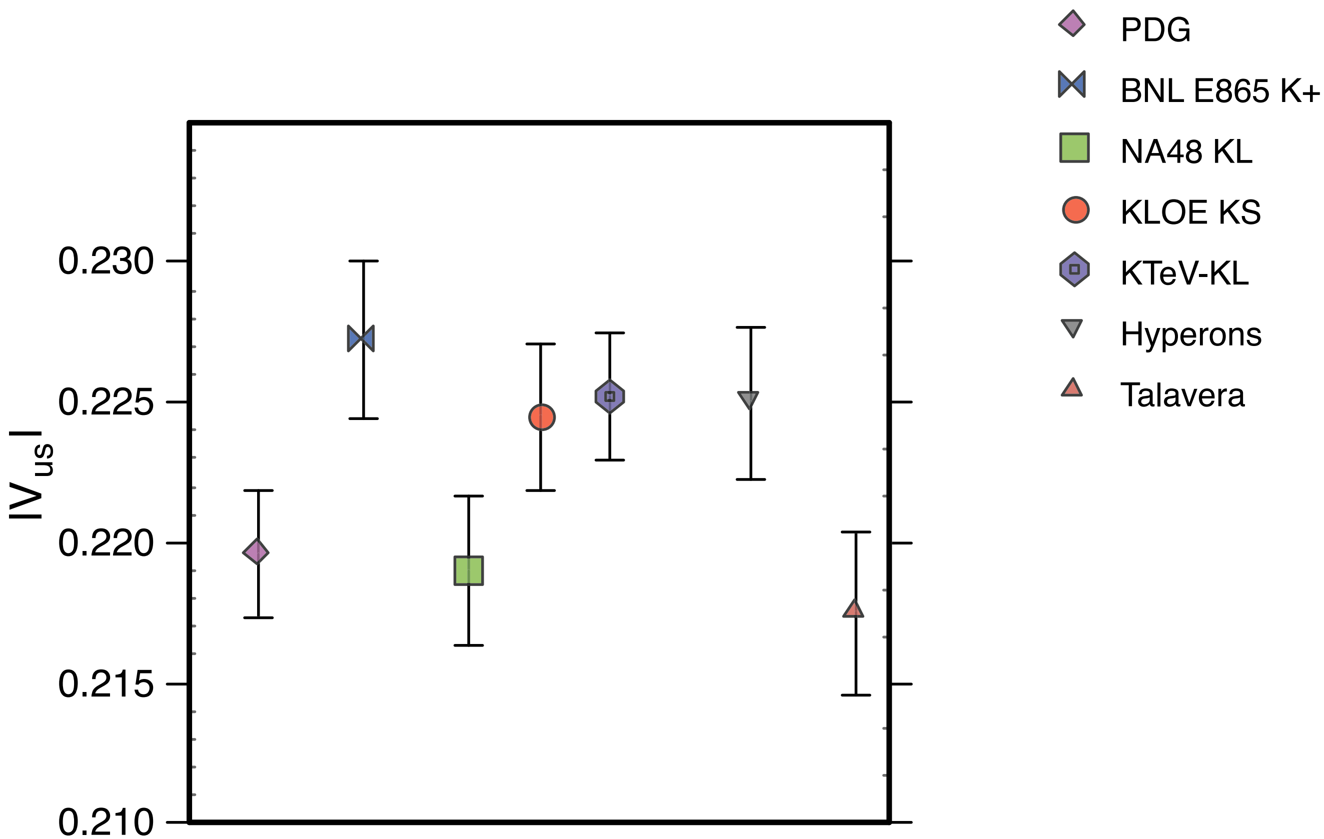
KTeV measures six ratios that enter extraction of $\Gamma(K_{\ell 3})$ Kessler



significant departures from PDG averages: $|\eta_{+-}|$ down 2.6%.

V_{us} *(and ingredients)*

Antonelli, Kleinknecht, Sher, Kessler, Talavera



KTeV supports K^+ value from E865, restores unitarity. Critical examination (e.g., form factors) needed, but seems to be a new era.

$\mathcal{CP}$ *violation in kaons*

$\triangleright$ $K^\pm$ in NA48 Maier

Asymmetries coming in $K^\pm \to \pi^\pm\pi^+\pi^-, \pi^\pm\pi^0\pi^0$
intend dedicated charged-kaon phase: $K^+ \to \pi^+\nu\bar{\nu}$

$\triangleright$ KTeV Ledovskoy

$K_L \to \pi^+\pi^-e^+e^-$: rare decay ($\sim 3 \times 10^{-7}$), large asymmetry

$$\boxed{\text{5241 candidates} \Rightarrow A = (13.7 \pm 1.4 \pm 1.5)\%}$$

Determination of charge radius $\langle R^2_{K^0} \rangle = (-0.077 \pm 0.014)$ fm^2

$\triangleright$ HyperCP Nelson

Mammoth samples of hyperon decays: $\mathcal{O}(10^9)$ Ξ, $\mathcal{O}(10^7)$ Ω

20-fold improvement in $\mathcal{CP}$ violation from $\Xi \to \Lambda \to p$ decay chain, expect
$\delta A_{\Xi\Lambda} \approx 2 \times 10^{-4}$ ($\approx 10\times$ SM, tests some new physics)

Parity violation in $\Omega \to K\Lambda$: $\alpha_\Omega = (1.8 \pm 0.2 \pm 0.1)\%$

$\mathcal{CP}$ violation, mixing in charm

▷ $\mathcal{CP}$ violation Asner: tiny in standard model

Current sensitivity $\mathcal{O}(10^{-2})$ from E791, FOCUS, CLEO, BaBar, Belle

$\rightsquigarrow 10^{-3}$ soon; 10^{-4} from CLEO-c and B factories in 5 years

Big step from BTeV, LHCb, . . .

▷ Charm mixing Flood: seems very small in standard model, but long-range contributions?

Current sensitivity to mixing amplitudes at few percent restricts some standard-model outliers, new physics proposals

FOCUS, BaBar, Belle, CLEO-c . . . BTeV, LHCb

$\mathcal{CP}$ *violation in* B *mesons*

Many new results, analyses in progress Yamamoto, Simani, Itoh, Ford

Rapid progress, multiple determinations and cross-checks

(Helen anticipated in some detail)

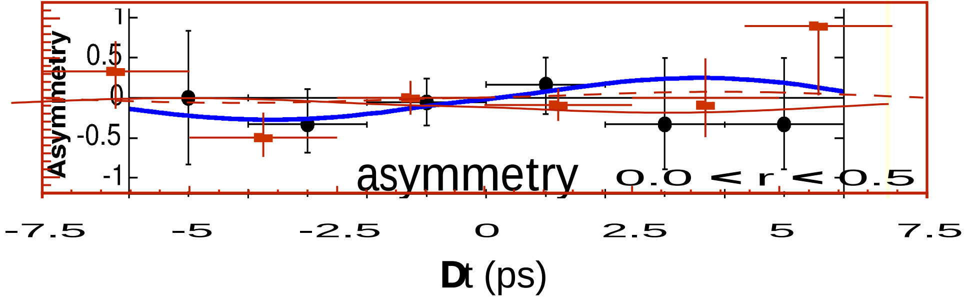
Golden mode ψK_S is golden (and ambiguities reduced)

$$\sin 2\beta = 0.731 \pm 0.056$$

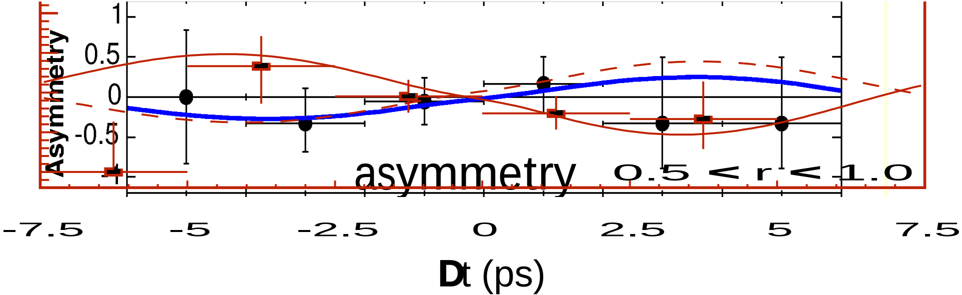
Some hint of troubles in $b \to s s \bar{s}$: differing values of $\sin 2\beta$ from Belle and BaBar in ϕK_S

Belle: "$\sin 2\phi_1$" $= -0.96 \pm 0.50^{+0.09}_{-0.11}$, 3.5σ from golden-mode value

A look at data (two overlay plots) suggests we wait and see



Asymmetry
1
0.5
0
-0.5
-1
asymmetry 0.0 < r < 0.5
-7.5
-5
-2.5
0
2.5
5
7.5
Dt (ps)



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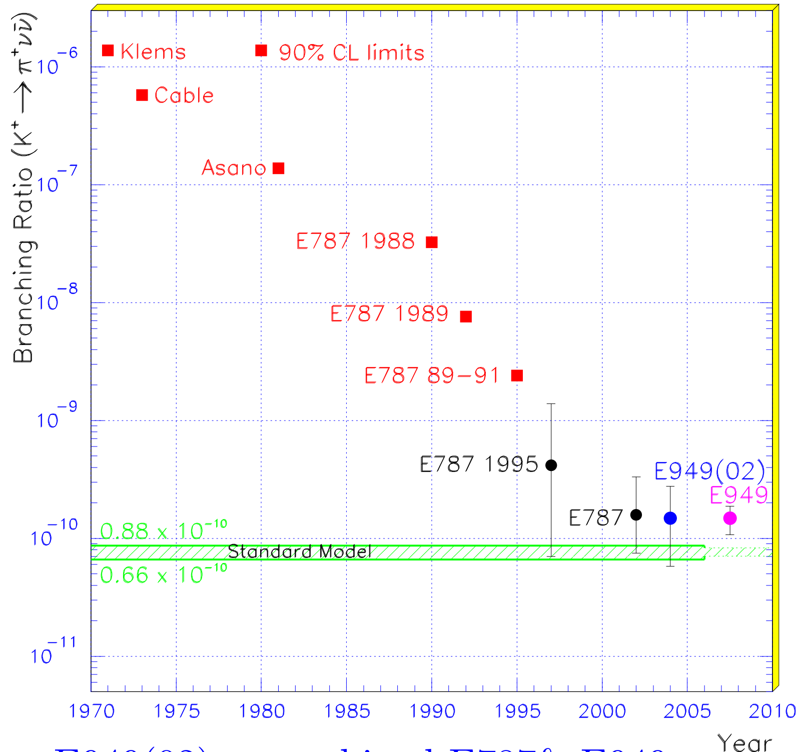
Dt (ps)

Rare Kaon Decays

E949: $K^+ \to \pi^+ \nu\bar{\nu}$ Jaffe adds one candidate to the two observed in E787

$$\boxed{B(K^+ \to \pi^+ \nu\bar{\nu}) = (1.47^{+1.30}_{-0.89}) \times 10^{-10}}$$



E949(02) = combined E787& E949.

E949 projection with full running period.

Rare Kaon Decays

NA48: K_S, K_L Velasco

First observations of

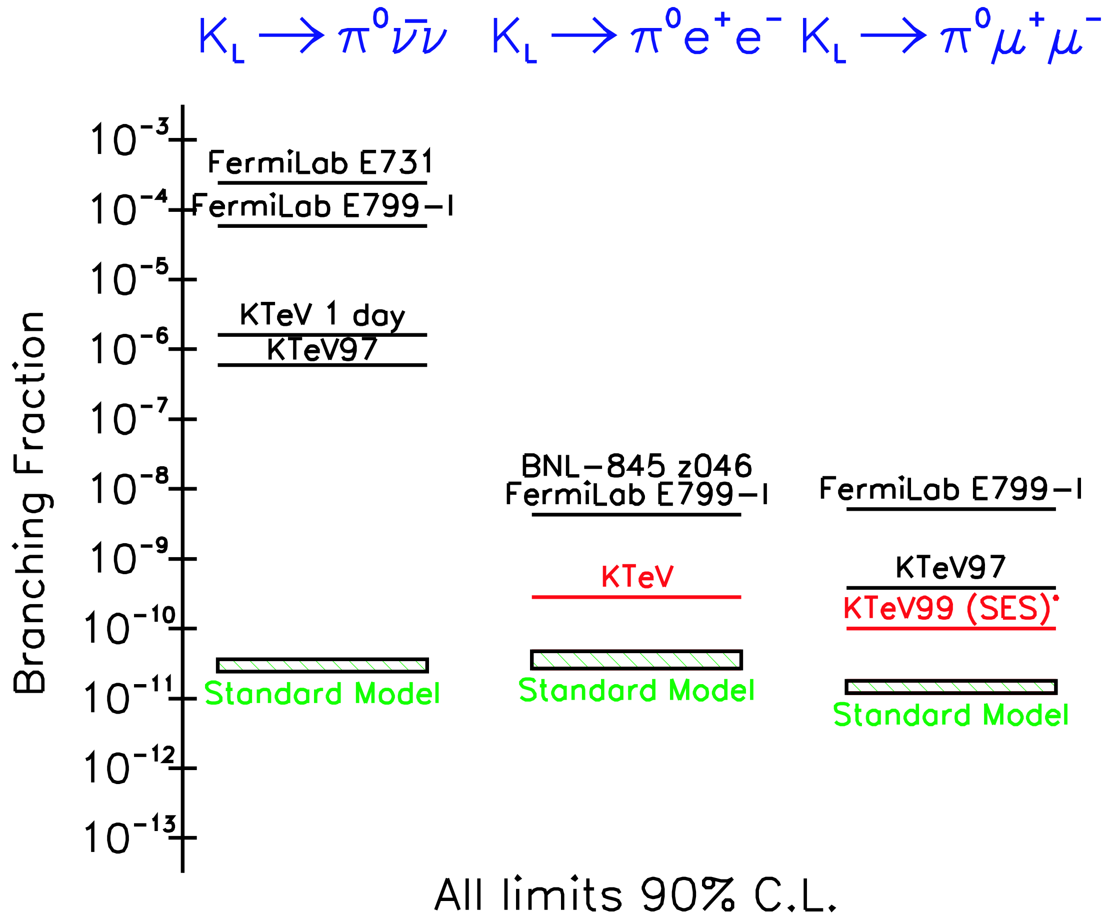
$$B(K_S \to \pi^0 e^+ e^-) = (5.8^{+2.8}_{-2.3} \pm 0.8) \times 10^{-9}$$
$$B(K_S \to \pi^0 \mu^+ \mu^-) = (2.9^{+1.4}_{-1.2} \pm 0.2) \times 10^{-9}$$

still 3 – 5 orders of magnitude above standard model

$$B(K_L \to e^+ e^- e^+ e^-) = (3.30 \pm 0.24 \pm 0.14 \pm 0.10_{\rm norm}) \times 10^{-8}$$

Rare Kaon Decays

KTeV: K_L Cheu



closing in on $\pi^0\ell^+\ell^-$, miles to go on $\pi^0\nu\bar{\nu}$

Rare B Decays

Chang, Jackson Great richness of decay modes and implications of rates and asymmetries.

Astonishing progress, from $b \to s\gamma$ to truly rare processes such as inclusive and exclusive $b \to s\ell^+\ell^-$ (measured around 10^{-6} level)

CDF also in play for $B_{d,s} \to \mu^+\mu^-$ Gómez-Ceballos

Many PV and VV modes measured at level of 10^{-5} or less.

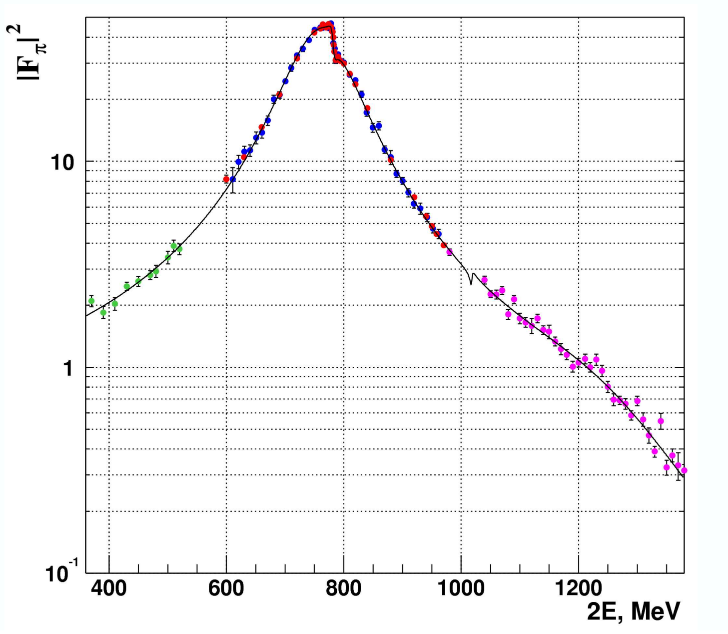
Challenge will be to extract all we can from a coherent analysis of rates, polarizations, asymmetries, etc.

Ultraprecise measurements

$(g-2)_\mu$ Morse

. . . now determined within $\pm 6 \times 10^{-10}$ (BNL E821)

Tantalizing comparison with standard model, $\Delta a_\mu = (24 \pm 10) \times 10^{-10}$
motivates improved theoretical evaluation (needs F_π Logashenko)
and constrains proposals for new physics



Lepton Flavor Violation

$\mu \to e\gamma$ Nicolò

A favored hunting ground for evidence of physics beyond (even simple extensions of) the standard model, including SUSY-GUTS

[See also EDMs Morse]

Current limit: MEGA, $B(\mu \to e\gamma) < 1.2 \times 10^{-11}$

MEG at PSI aims to improve by two orders of magnitude, using some SUSY models for target practice

(possible program of a future muon storage ring / neutrino factory)

Neutrino Properties

Much has been settled in a few years. Many pressing questions.

Both past and future: diversity of approaches—natural sources, reactors, accelerators, . . .

$\triangleright$ Refine knowledge of primary oscillation modes Kajita, Ereditato, Parke seeing oscillatory behavior, (θ_{23})

$\triangleright$ Track down LSND (doesn't fit three flavors) Stancu

$\triangleright$ Determining θ_{13} Link, Diwan, Parke
Reactors $\rightarrow 10^{-2}$, LBL $\rightarrow \frac{1}{2}10^{-2}$, ν factory $\rightarrow 10^{-4}$

$\triangleright$ $\mathcal{CP}$ violation? Observe matter effects

$\triangleright$ Determine mass hierarchy

$\triangleright$ Majorana? $(\beta\beta)_{0\nu}$ Giuliani 10^{26} y $\Leftrightarrow 1$ decay/y/100 moles !

$\triangleright$ Lightest neutrino mass: tritium β decay Bonn Now < 2.3 eV
KATRIN aims for 0.2 eV limit, 0.35 eV observation (cosmo input)

Neutrino applied science

▷ Using neutrinos to learn about the Universe and how it works Langacker

UHE neutrino astronomy — diffuse glow of AGNs, GRBs?

Relic neutrinos (10^7 inside your body) — can we detect, study?

Contributions to dark matter budget, structure formation

Leptogenesis?

Astrophysical problems like supernovae

. . .

Heavy-quark production

$\triangleright$ Tevatron Collider Gómez-Ceballos

The expected rich program plus some nice surprises:

- Large prompt charm samples
- CDF: Excellent measurements of b-hadron masses, e.g., $M(\Lambda_b) = (5619.7 \pm 1.2 \pm 1.2)$ MeV (compare PDF (5624 ± 9) MeV))
- DØ: Observation of $B \to \mu\nu D^{**} + \ldots$

The killer app, B_s mixing, is still some time (and luminosity) away

Heavy-quark production

▷ CHORUS Di Capua

2059 charm events in hybrid emulsion ν $(20\times$ E531$)$

charm fractions, fragmentation functions, etc. to come soon!

▷ ep collisions at HERA Sefkow

heavy-flavor parton distributions, tool to constrain gluon distribution, fragmentation distributions

future: search for anomalous single-top production, motivated by hint of isolated leptons at high $p_\perp$

Heavy-quark decays

▷ Charm and beauty lifetimes Boca

Some evolution of averages, the promise of improved b lifetimes from the Tevatron experiments, but the classic problems for heavy-quark models remain:

$\tau(\Lambda_b)/\tau(B_d) = 0.776 \pm 0.040$, expect 0.90 ± 0.05

$\tau(B_s)/\tau(B_d) = 0.926 \pm 0.033$, expect 1.00 ± 0.01

Many charm lifetimes are highly precise, progress over past four years, in general agreement with expected systematics.

▷ The power of Dalitz-plot analysis Moroni, Kutschke

The Spectroscopy Renaissance

$\boxed{\eta_c',\ D_{sJ},\ \Theta^+ \text{ and friends, } X(3872),\ \text{“}j_q = \tfrac{1}{2} \text{ levels”}}$

(. . . also many revised properties)

▷ η_c': Metreveli, Barnes

1 of 4 expected missing narrow states $(+1^1\mathrm{P}_1, 1^1\mathrm{D}_2, 1^3\mathrm{D}_2)$

Well established, properties converging

$M(\psi') - M(\eta_c') = 48.3 \pm 4.4$ MeV; potential models ≈ 67 MeV

coupling to open charm reduces by ≈ 21 MeV   correct interpretation?

The Spectroscopy Renaissance

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(…also many revised properties)

- D_{sJ}: Barnes, Guler, Kutschke

  Well established, properties converging

  J^{PC} seem consistent with $j_q = \frac{1}{2}$ $c\bar{s}$ levels,

  but centroid well below $j_q = \frac{3}{2}$, so quite narrow

  Is there a simple, graceful interpretation?

  $c\bar{s}$ or DK "multiquark, molecule"

  need predictions, tests of branching fractions …

  Does chiral symmetry link multiplets with same j_q and $L = \ell, \ell + 1$?

$\boxed{\text{What happens in } B_s \text{ system?}}$

(Meson classification schemes)

Compare LS and jj coupling in atoms

Choice of basis (mis)guides our thinking ...

$\triangleright$ Equal-mass $q\bar{q}$ or $Q\bar{Q}$: Couple $\vec{L}$ with $\vec{S} = \vec{s}_q + \vec{s}_{\bar{q}}$

Standard for light mesons, now familiar for $c\bar{c}$, $b\bar{b}$
$\Rightarrow$ ${}^1\mathrm{S}_0$ – ${}^3\mathrm{S}_1$; ${}^1\mathrm{P}_1$ – ${}^3\mathrm{P}_{0,1,2}$; ${}^1\mathrm{D}_2$ – ${}^3\mathrm{D}_{1,2,3}$; ${}^1L_L$ – ${}^3L_{L-1,L,L+1}$

$\triangleright$ Heavy=light $Q\bar{q}$: Couple $\vec{s}_Q$ with $\vec{j}_q = \vec{L} + \vec{s}_q$
$L = 0$: $j_q = \frac{1}{2}$: 0^- – 1^-
$L = 1$: $j_q = \frac{3}{2}$: 1^+ – 2^+ (d-wave decay); $j_q = \frac{1}{2}$: 0^+ – 1^+ (s-wave decay)

Strange particles ($s\bar{q}$): Traditional $q\bar{q}$ classification, but maybe insights from considering as $Q\bar{q}$?

Seek out intermediate cases ($B_c = b\bar{c}$): Mixed 1^+ levels

Where does D_s system lie?

The Spectroscopy Renaissance

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(. . . also many revised properties)

▷ Θ^+ and friends: Lipkin, Stanco, Tedeschi

No state established, several signals worth pursuing

$\Theta^+(1540)$ with K^+n quantum numbers Many inconclusive sightings
$\Xi^{--}(1860)$ NA49 yes, WA89, Zeus, CDF no
$\Theta_c^0(3099) \to D^{*-}p$ H1 yes, Zeus no

$\boxed{\text{No theory with quantifiable uncertainties; what can we learn?}}$

Interest: What is a hadron? What are apt degrees of freedom? What symmetries are fruitful? Complete multiplets??

The Spectroscopy Renaissance

$\boxed{\eta_c',\ D_{sJ},\ \Theta^+ \text{ and friends, } X(3872),\ \text{“}j_q = \tfrac{1}{2} \text{ levels”}}$

(...also many revised properties)

▷ $X(3872) \to \pi^+\pi^- J/\psi$: Barnes, Guler, Gomez-Ceballos

Well established, J^{PC} not determined

Seen in B decay, also (almost certainly) prompt production

Mass nearly coincides with $D^0\bar{D}^{*0}$

We do not know what $X(3872)$ is

$^3\mathrm{D}_2$ (or perhaps $^3\mathrm{D}_3$) $c\bar{c}$ plausible *a priori,* radiative decays not seen; coupling to open charm important

$\boxed{\text{New spectroscopy of discrete } D^{(*)}\bar{D}^{(*)} \text{ levels?}}$

Charm molecule analogue of deuteron; production?

Important: J^{PC}, $\pi^0\pi^0 J/\psi$, $\Gamma(\psi(3770) \to \pi\pi J/\psi)$ ...

The Spectroscopy Renaissance

$\boxed{\eta_c',\ D_{sJ},\ \Theta^+ \text{ and friends, } X(3872),\ \text{“}j_q = \tfrac{1}{2} \text{ levels”}}$

(. . . also many revised properties)

▷ “$j_q = \frac{1}{2}$ levels”: Kutschke

Beginning to have quantitative information about $c\bar{q}$ levels

Evolution of technique to incorporate Dalitz plot analysis

What can theory say? learn?

New start: CLEO-c

First running on $\psi(3770)$ as a D-factory Yelton

Promises 2 to 3 *orders of magnitude* increase in tagged D-mesons . . .

Example: First measurement of

$$B(D^+ \to \mu^+\nu_\mu) = (4.57 \pm 1.66 \pm 0.41) \times 10^{-4},$$
$$\rightsquigarrow f_D = (230 \pm 42 \pm 10) \text{ MeV}$$

$60\times$ statistics coming!

Compare UKQCD lattice calculation: $(210 \pm 10^{+17}_{-16})$ MeV

Other early results on $\sigma(D\bar{D})$, D semileptonic decays . . .

CKM Matrix Elements from D and B

▷ Dialogue between theory and experiment essential Gray, Bauer

Lattice: unquenched calculations becoming the standard, error estimates have an objective meaning. "Golden quantities" include many of interest to experiment: pseudoscalar decay constants, semileptonic form factors, etc. Continuing conversation needed to realize the potential of this new tool

Prodigious amount of information on charm semileptonic form factors ready to confront unquenched calculations Wiss

Heavy-quark symmetry and its offspring: toward systematic, controlled expansions useful for experiment.

CKM Matrix Elements from D and B

▷ New experimental determinations

$|V_{cb}|$ from BaBar Fortin

inclusive: $(4.14 \pm 0.04 \pm 0.04 \pm 0.06) \times 10^{-2}$

$D^*\ell\nu$: $(3.727 \pm 0.026 \pm 0.143^{+0.148}_{-0.123}) \times 10^{-2}$

$|V_{cb}|$ from CLEO Stepaniak

$b \to c\ell\nu$ moments, HQET: $(4.206 \pm 0.081) \times 10^{-2}$

$|V_{ub}|$ from Belle Schwanda
many new techniques for $B \to u\ell\nu$ and exclusives

HFAG average: $(4.57 \pm 0.61) \times 10^{-3}$

The role of flavor physics

$\boxed{\text{All fermion masses and mixings mean new physics}}$

▷ What sets masses & mixings of quarks & leptons?

▷ What makes an electron an electron and a top quark a top quark?

▷ The flavor scale(s): at what energy scales are the properties of the fundamental fermions determined? (Are they the same for neutrinos as for quarks and charged leptons?)

▷ What is $\mathcal{CP}$ violation trying to tell us?

▷ Neutrino oscillations give us another take, might hold a key to the matter excess in the universe.

▷ Will new kinds of matter help us see the pattern? sterile neutrinos, superpartners, dark matter . . .

Some impressions and thoughts

▷ Enormous vitality and richness of the experiments. They are extremely valuable institutions, especially when resourceful and nimble.

How do we continue to create such institutions? More layers of review are not the answer.

▷ Competition is stimulating and improves our science, but one superb experiment is worth more than several fainter efforts.

How can we cooperate more effectively—among labs and regions—to get the most out of our science?

▷ The dialogue between experiment and theory is indispensable, but it is too little supported, especially in American universities.

Experimenters must demand more from their theoretical colleagues, and the agencies could offer gentle encouragement.

Some impressions and thoughts

▷ It is essential to keep in mind the connections with new physics — the unknown physics.

When new forms of matter are found, habits of mind and styles of analysis developed in flavor physics will be much in demand. Young people (especially) should think of moving between different kinds of experiments.

▷ Answers — or at least pregnant questions — may come from unexpected quarters.

Extra dimensions, for example, give a new take on fermion masses.

▷ Important to think coherently about quarks and leptons—the problem of identity.

Measurements we make over the next decade will help to frame the question, point to the future.


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